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Leading Innovation

Simulation of an Electron Gun for ERL-FEL Based EUV Lithography System

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Toshiba Corporation
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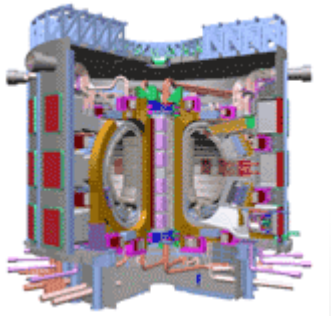
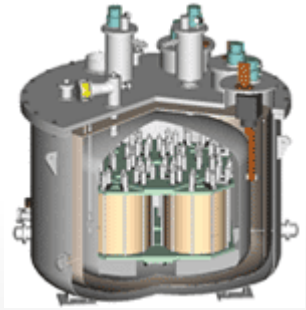
Background

Toshiba Power Systems Company





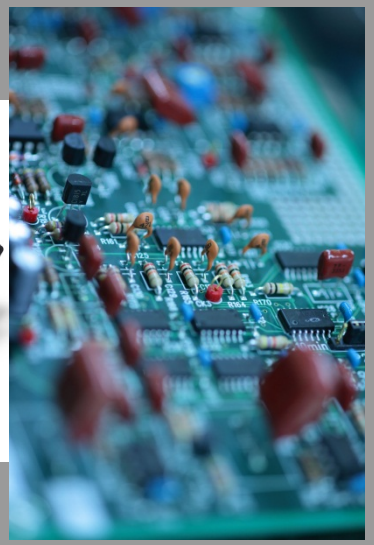
Super conducting technology

Particle accelerator facility

superconducting cavity

Plant technologies

Toshiba Semiconductor & Storage Products Company

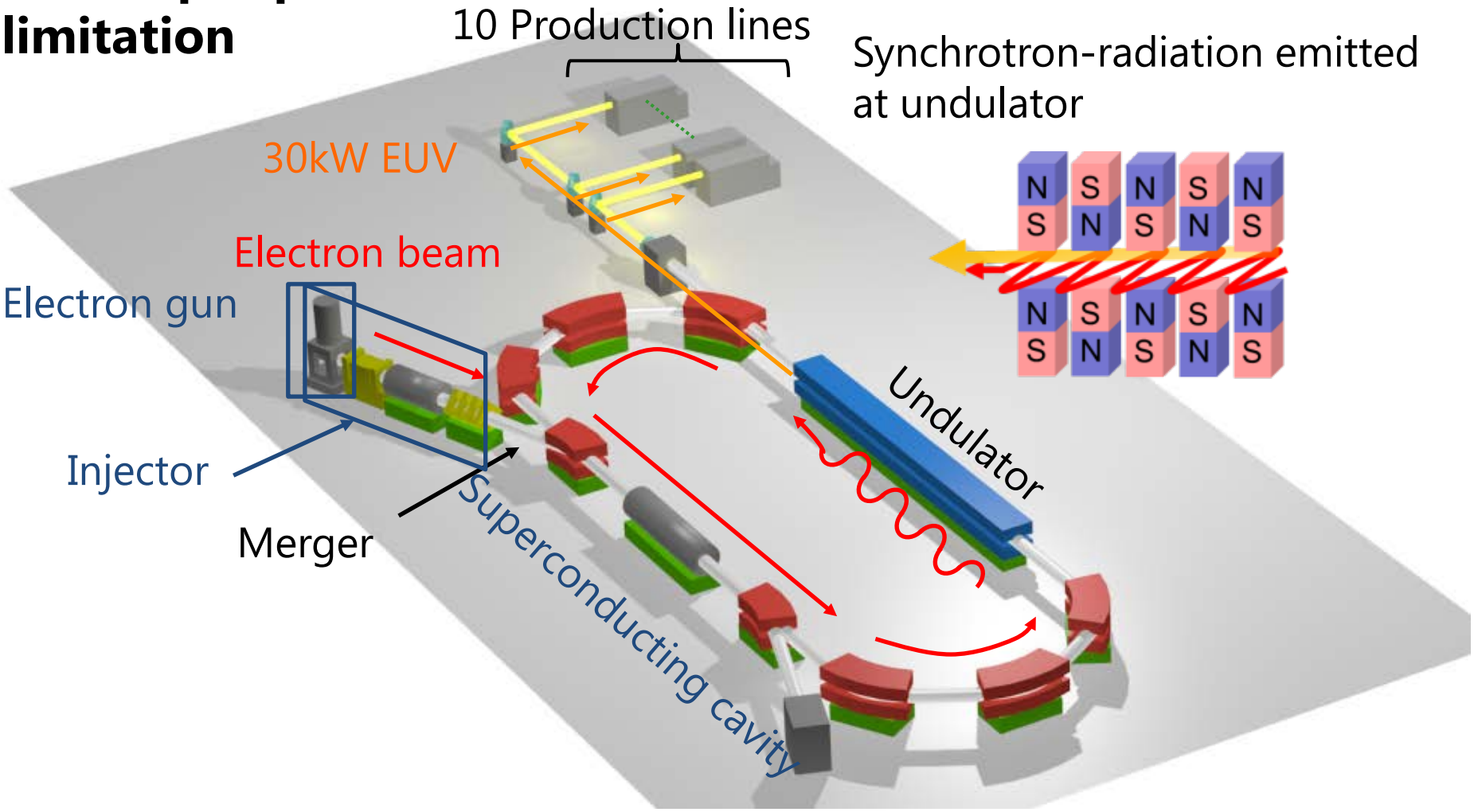


Semiconductor

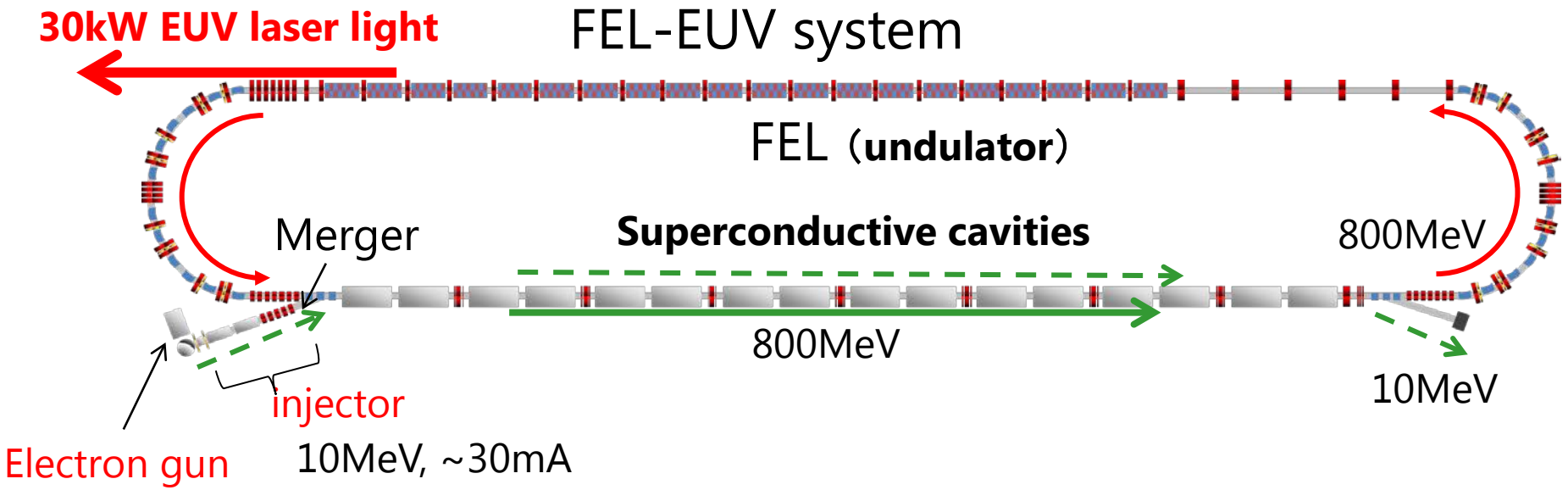
Toshiba has both accelerator and semiconductor in-house companies.

Background

- **LPP<500W (Current level ~100W)**
- **FEL output power scales with electron beam current: no limitation**



Base Design

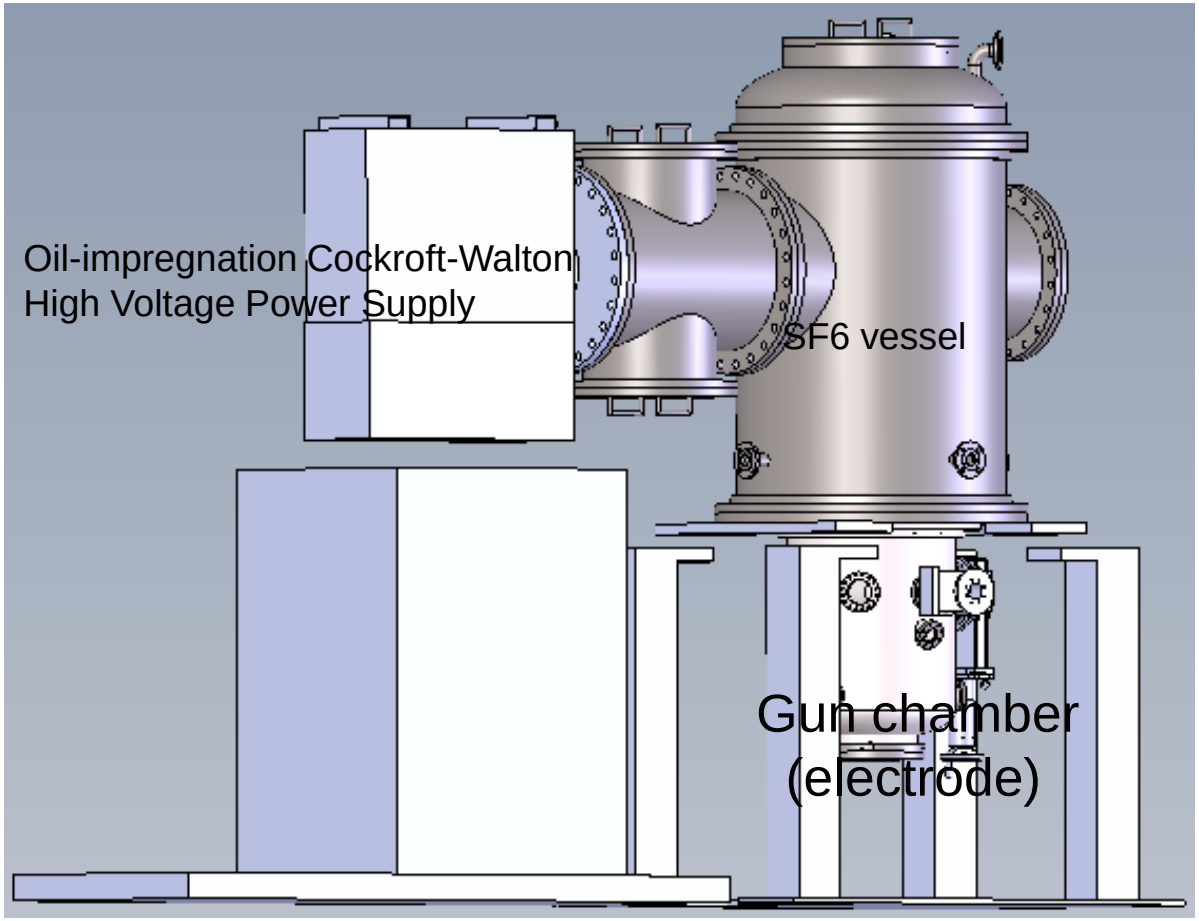


- **Electron gun and injector: critical components**
- **We designed electron gun and injector based on cERL.**

Accelerator parameters

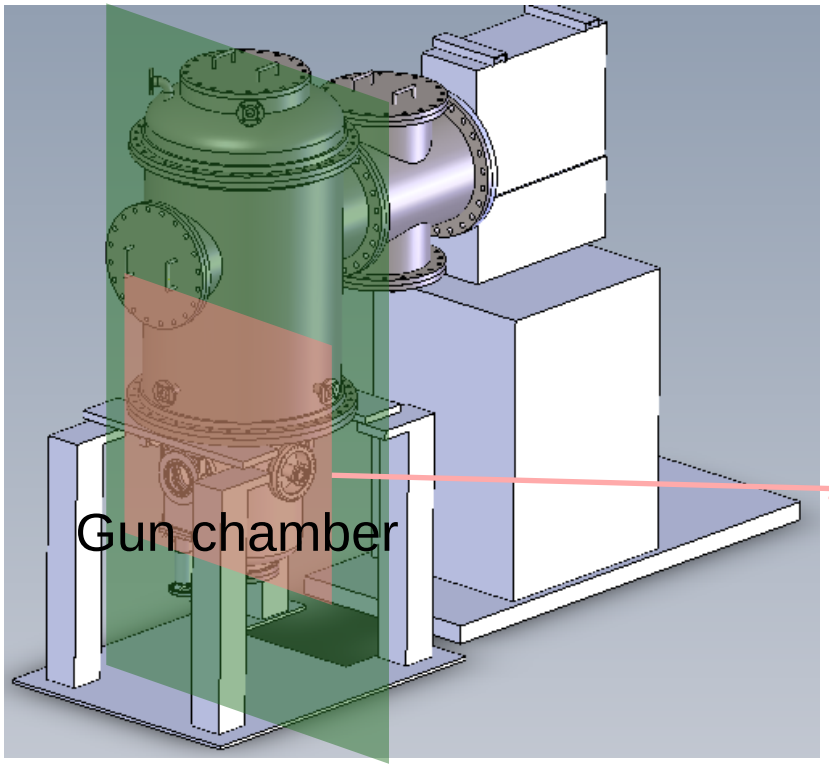
	FEL-EUV light source	cERL
Energy[MeV]	800	35
Bunch charge[pC]	60 or 100	77
Emittance[mm・mrad]	0.8(100pC) or 0.6(60pC)	1
Average current[mA]	10⇒30(upgrade)	10
FEL Power[kW]	10⇒30(upgrade)	–

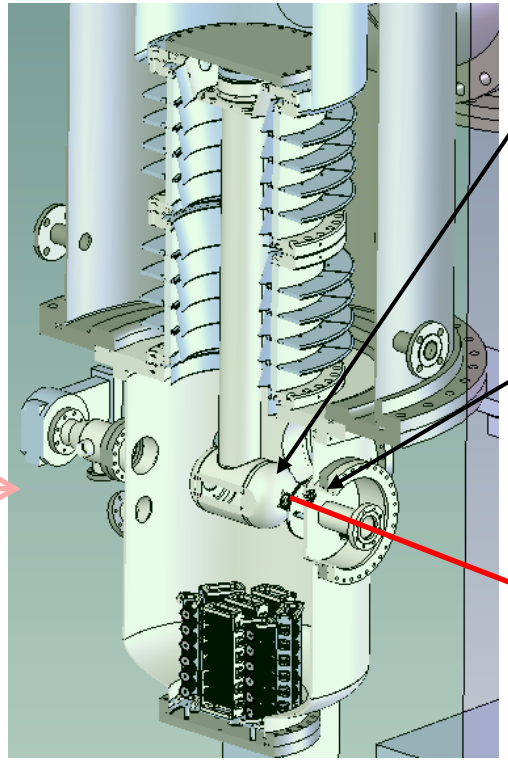
Electron gun

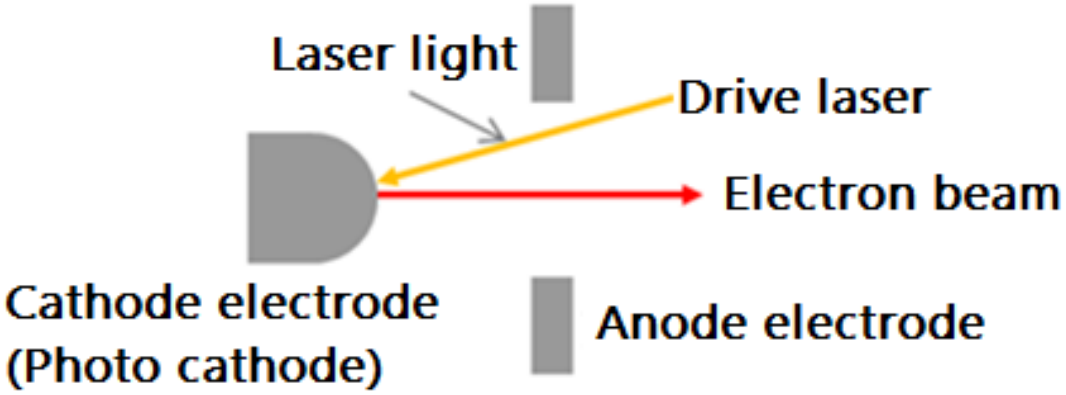


cERL uses 500-keV electron gun

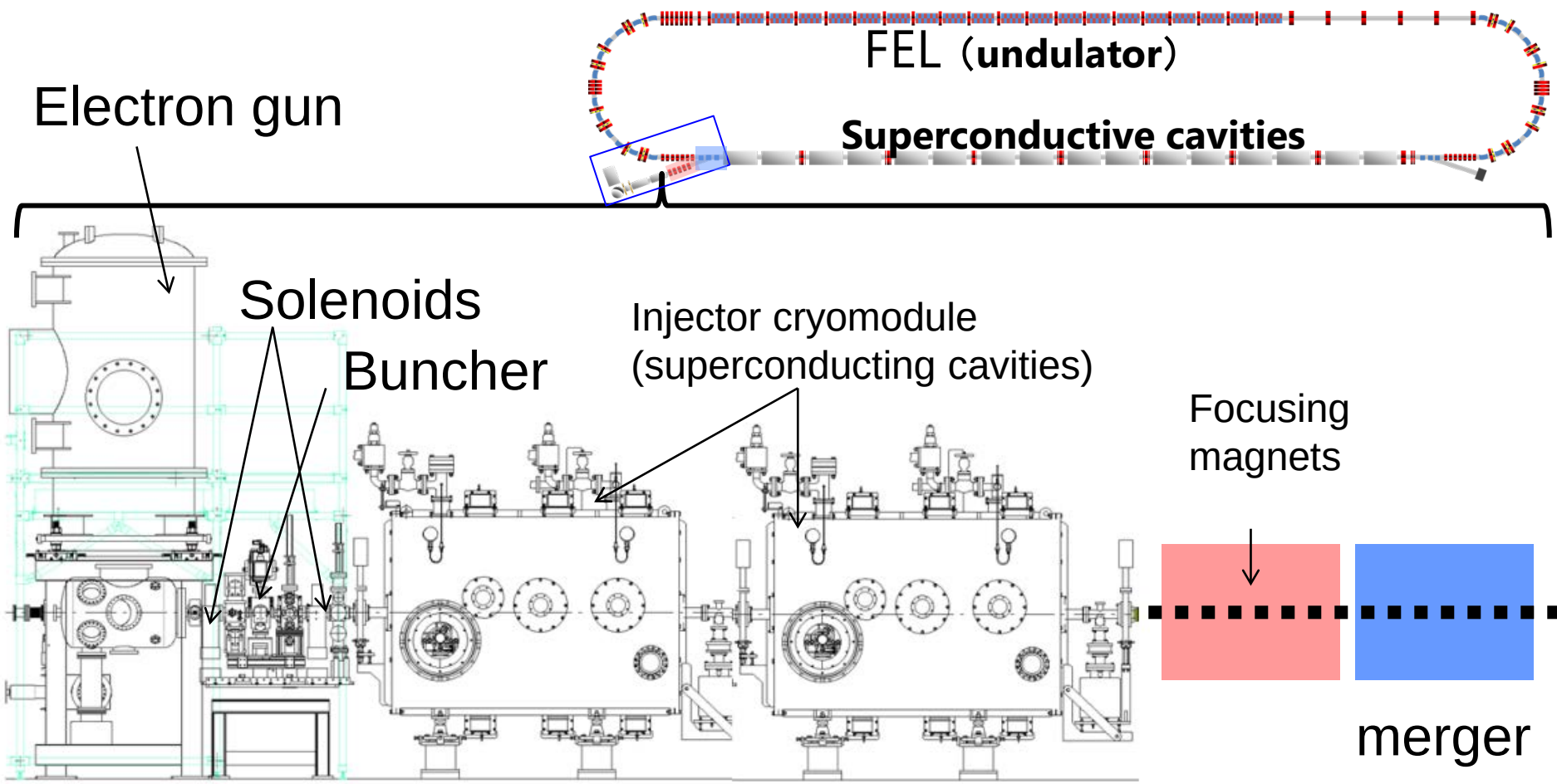
Photo cathode





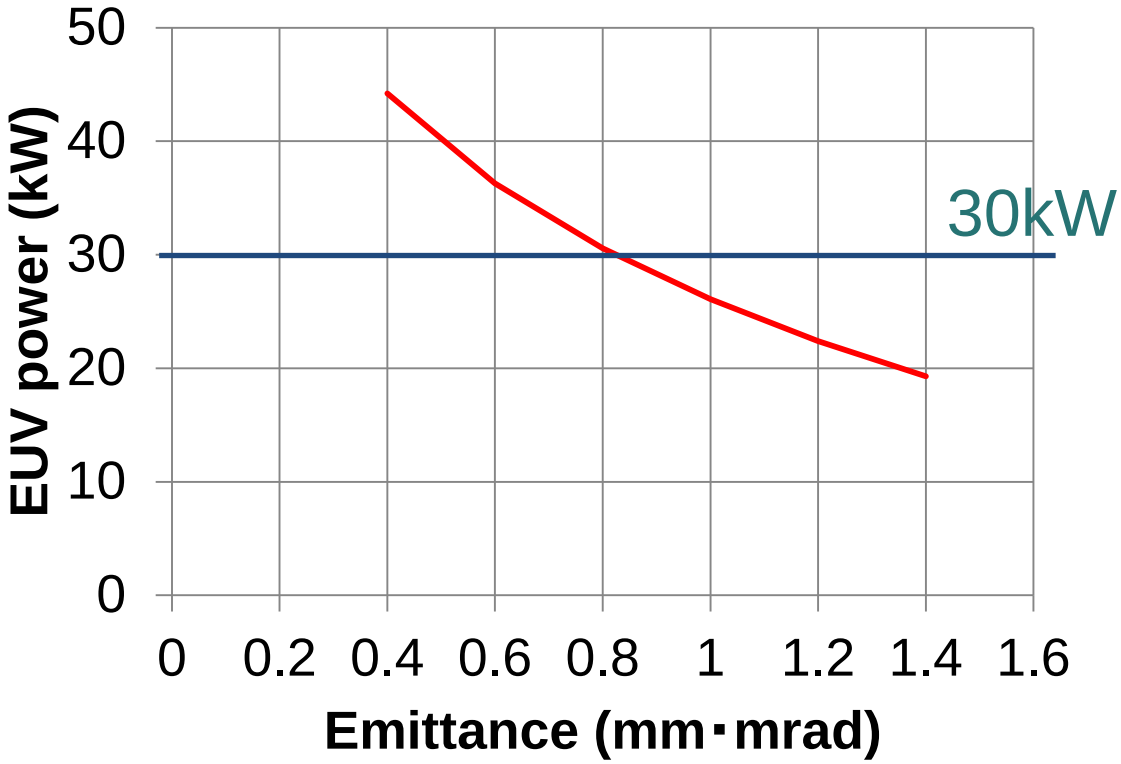


Injector



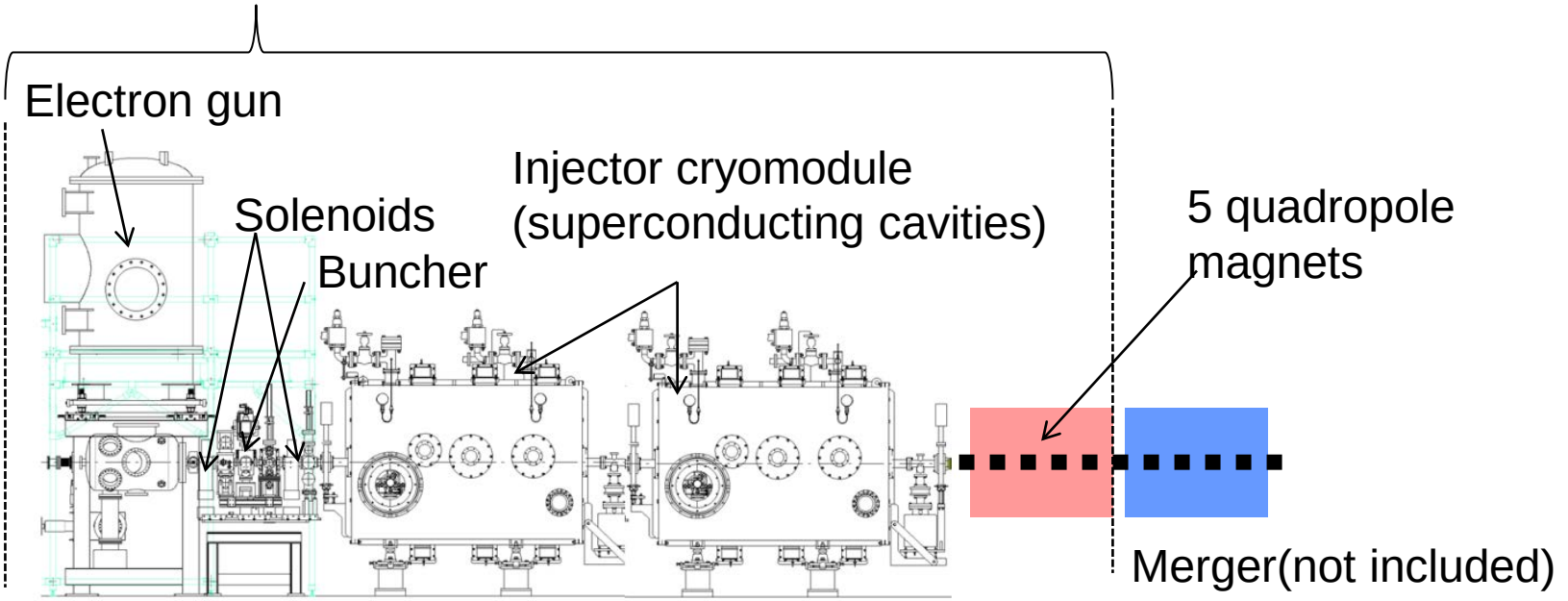
Emittance

- **Emittance: a measure for the average spread of particle coordinates in position-and-momentum phase space.**
- **<u>EUV power inversely scales with emittance</u>**

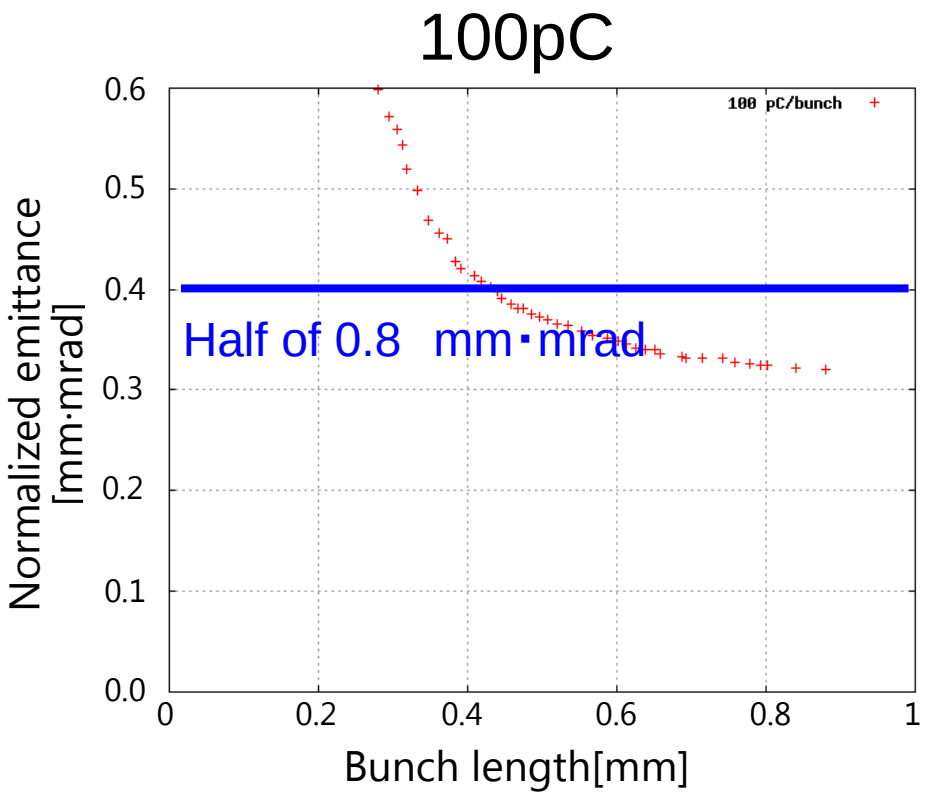


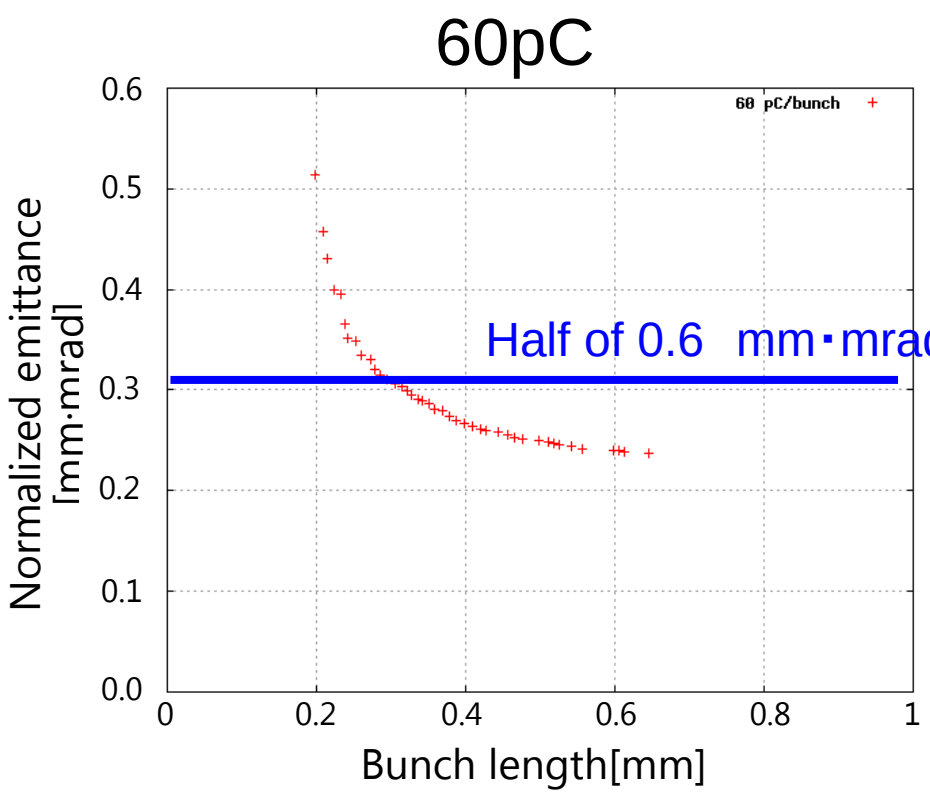
Optimized parameters

	fixed value	optimizing paramator
electrode shape of electron-gun	the same as those of cERL	-
electrode voltage[kV]	500	-
Bunch charge[pC]	60 or 100	-
Initial emittance[eV]	0.14(Multi-Alkali Cathode)	-
cryomodule	2 units (the same as those of cERL)	location, rf phase
buncher cavity	1 unit (the same as that of cERL)	location, rf phase
solenoid	2 units (the same as those of cERL)	Location, strength of magnetic field
quadropole magnet	9 units (the same as those of cERL)	location, strength of magnetic field



Injector simulation





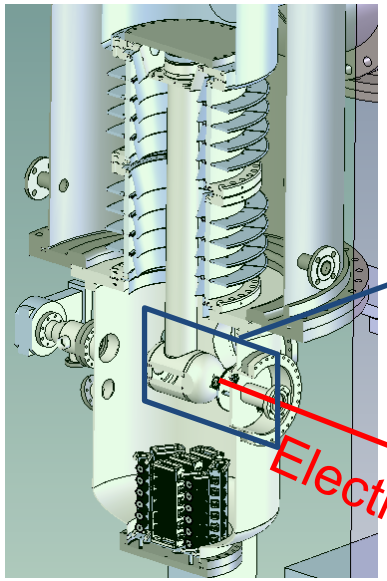
Merger not included in the simulation.

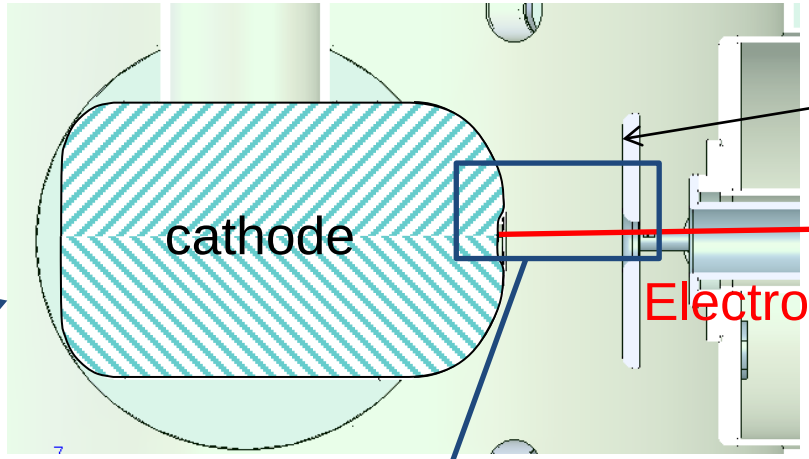
Factor of ~2 growth in the emittance at the merger section.

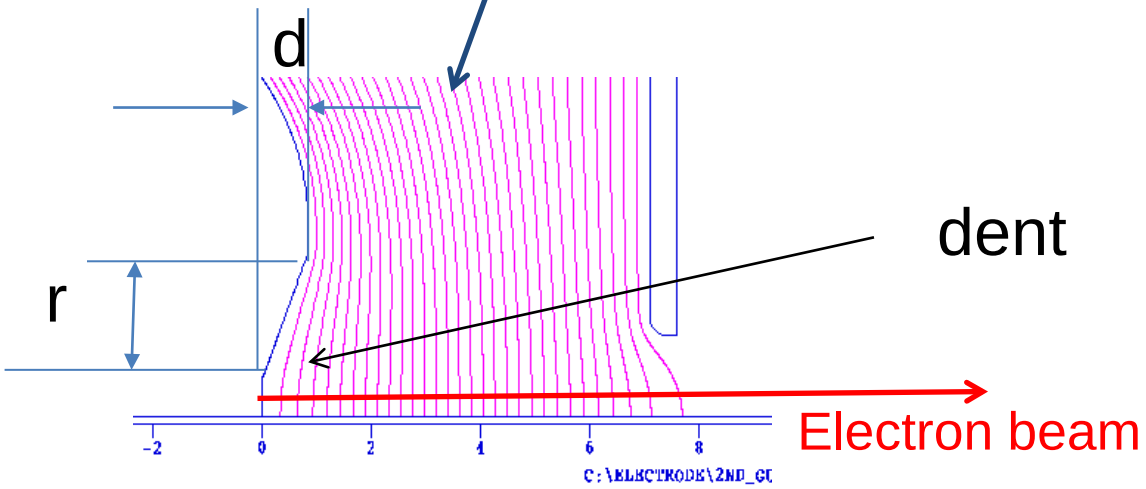
Goal: 0.6mm･mrad(60pC) or 0.8mm･mrad(100pC) at the end of merger section.

Electrode

Calculation condition

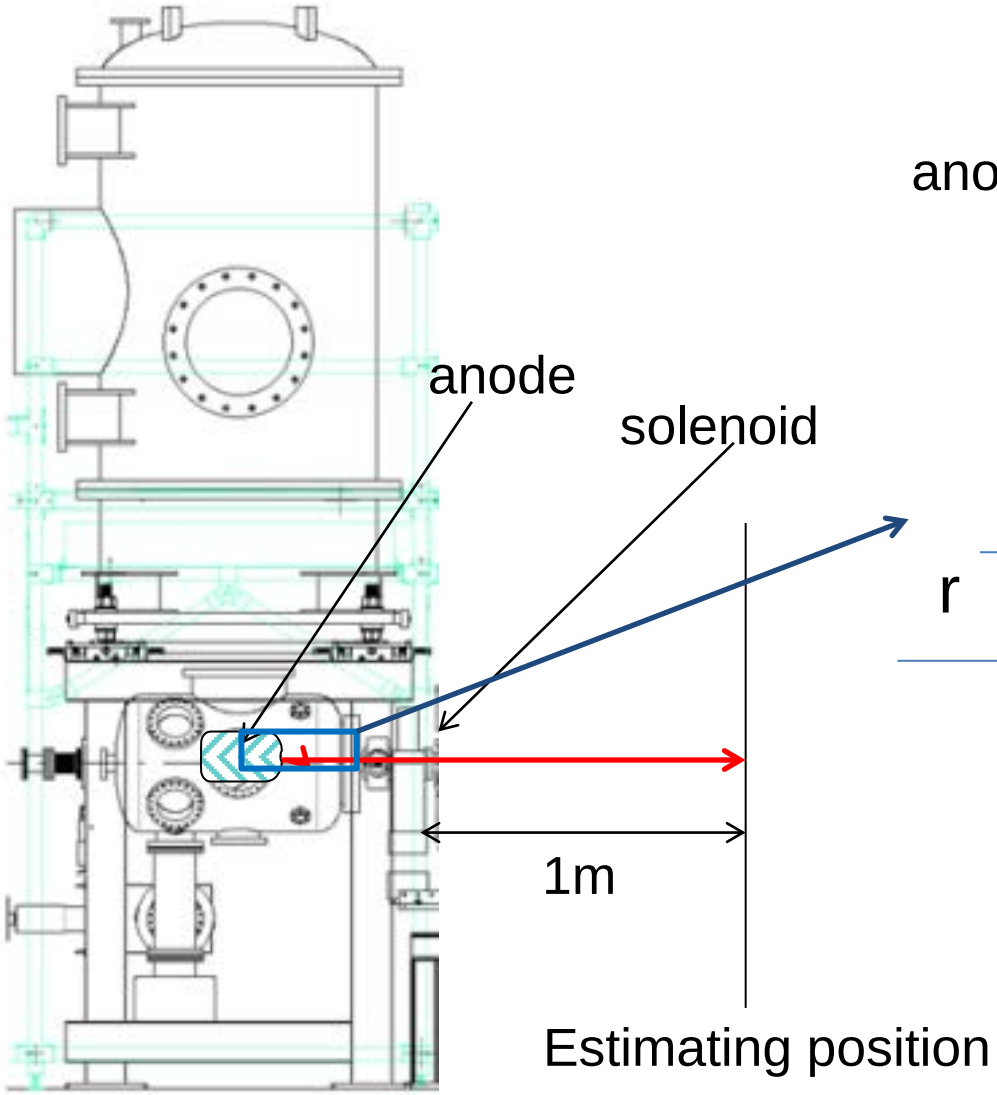


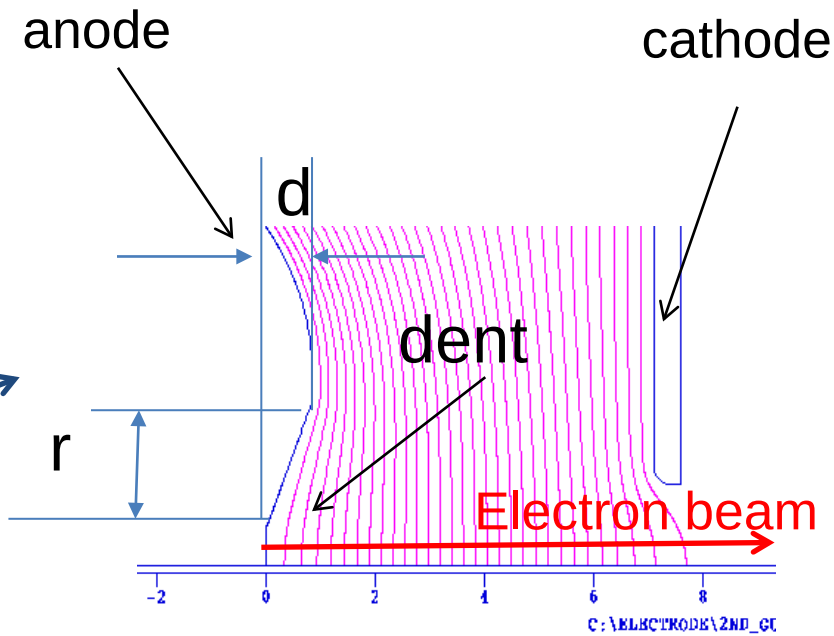




- Bunch charge 100pC
- Beam size 1mm
- Laser pulse 64ps
- Laser shape Beer can
- Initial emittance k_BT=0.14eV (Multi-Alkali Cathode)

Calculation system





Parameter range
r: 0~30mm
d:1~11mm

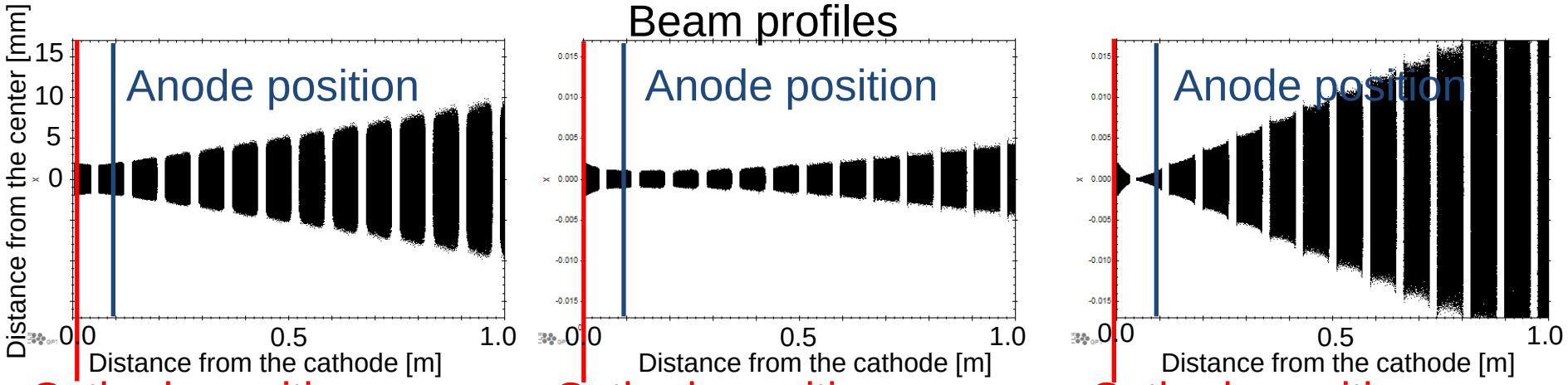
Result

r=7.5mm d=3mm (original) ε=0.64mm･mrad → 10% smaller → r=7.5mm d=5.6mm ε=0.57mm･mrad → r=0mm d=5mm ε=1.66mm･mrad

Small ⟶ d/r ⟶ Large

Large ⟵ Emittance smallest ⟶ Large

Beam profiles



Weak ⟶ Focusing ⟶ Strong

Low ⟶ Divergence lowest ⟶ Low

Emittance stayed almost the same (10 % smaller), however, beam divergence became smaller.

⇒ Influence of magnetic field fluctuation can be reduced.

Conclusion

- **We have been designing FEL-based EUV source for lithography.**
- **Optics using cERL component can achieve small beam emittance needed for EUV lithography.**
- **Preliminary design of an electron gun was made based on simulation studies.**
- **Electrode geometry has a small effect on emittance, and large effect on beam divergence.**

Our next step is

- **To optimize parameters including merger section.**
- **To evaluate influence of small beam diameter.**
- **To make a prototype product to evaluate influence of large current and life time of the electrode.**

Working group

- **Working group formed recently to promote FEL-based EUV for lithography.**
- **Member: KEK, GPI, Toshiba and other companies related to semiconductor and lithography.**
- **The goal is to develop a prototype around 2020.**

- **We welcome everyone to join the working group.**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